Chapter 10
Post-processing Differential GPS Observational Data

10-1. General

GPS baseline solutions are usually generated through an iterative process. From approximate values of the positions occupied and observation data, theoretical values for the observation period are developed. Observed values are compared to computed values, and an improved set of positions occupied is obtained using least squares minimization procedures and equations modeling potential error sources.

a. Processing time is dependent on the accuracy required, software development, computer hardware used, data quality, and amount of data. In general, high accuracy solutions, crude computer software and hardware, low-quality data, and high volumes of data will cause longer processing times.

b. The ability to determine positions using GPS is dependent on the effectiveness of the user to determine the range or distance of the satellite from the receiver located on the earth. There are two general techniques currently operational to determine this range: pseudo-ranging and carrier beat phase measurement. These techniques are discussed in further detail below.

c. The user must take special care when attempting a baseline formulation with observations from different GPS receiver manufacturers. It is important to ensure that observables being used for the formulation of the baseline are of a common format (i.e., RINEX). The common data exchange formats required for a baseline formulation exist only between receivers produced by the same manufacturer, but there are some exceptions.

d. This chapter will discuss general post-processing issues. Due to the increasing number and variety of software packages available, consult the manufacturer guidelines when appropriate.

10-2. Pseudo-Ranging

The pseudo-range observable is calculated from observations recorded during a GPS survey. The pseudo-range observable is the difference between the time of signal transmission from the satellite, measured in the satellite time scale, and the time of signal arrival at the receiver antenna, measured in the receiver time scale. When the differences between the satellite and the receiver clocks are reconciled and applied to the pseudo-range observables, the resulting values are corrected pseudo-range values. The value found by multiplying this time difference by the speed of light is an approximation of the true range between the satellite and the receiver, or a true pseudo-range. A more exact approximation of true range between the satellite and receiver can be determined if ionosphere and troposphere delays, ephemeris errors, measurement noise, and unmodeled influences are taken into account while pseudo-ranging calculations are performed. The pseudo-range can be obtained from either the C/A-code or the more precise P-code (if access is available).

10-3. Carrier Beat Phase Observables

The carrier beat phase observable is the phase of the signal remaining after the internal oscillated frequency generated in the receiver is differenced from the incoming carrier signal of the satellite. The carrier beat phase observable can be calculated from the incoming signal or from observations recorded during a GPS survey. By differencing the signal over a period or epoch of time, one can count the number of wavelengths that cycle through the receiver during any given specific duration of time. The unknown cycle count passing through the receiver over a specific duration of time is known as the cycle ambiguity. There is one cycle ambiguity value per satellite/receiver pair as long as the receiver maintains continuous phase lock during the observation period. The value found by measuring the number of cycles going through a receiver during a specific time, when given the definition of the transmitted signal in terms of cycles per second, can be used to develop a time measurement for transmission of the signal. Once again, the time of transmission of the signal can be multiplied by the speed of light to yield an approximation of the range between the satellite and receiver. The biases for carrier beat phase measurement are the same as for pseudo-ranges although a higher accuracy can be obtained using the carrier. A more exact range between the satellite and receiver can be formulated when the biases are taken into account during derivation of the approximate range between the satellite and receiver.

10-4. Baseline Solution by Linear Combination

The accuracy achievable by pseudo-ranging and carrier beat phase measurement in both absolute and relative positioning surveys can be improved through processing that incorporates differencing of the mathematical models of the observables. Processing by differencing takes advantage of correlation of error (e.g., GPS signal, satellite ephemeris, receiver clock, and atmospheric propagation errors) between receivers, satellites, and epochs, or combinations thereof, in order to improve GPS processing. Through differencing, the effects of the errors that are common to the observations being processed are eliminated or at least greatly reduced. Basically, there are three broad processing techniques that incorporate differencing: single differencing, double differencing, and triple differencing. Differenced solutions generally proceed in the following order: differencing between receivers takes place first, between satellites second, and between epochs third.

a. Single differencing. There are three general single differencing processing techniques: between receivers, between satellites, and between epochs (see Figure 10-1).

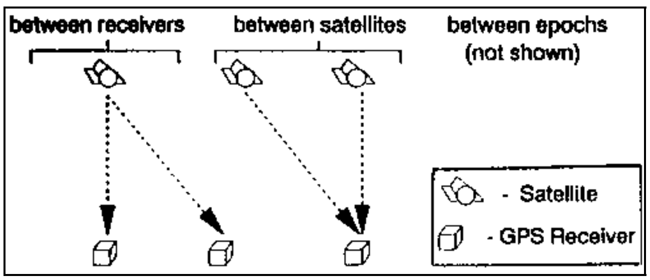


Figure 10-1. Single differencing

(1) Between receivers. Single differencing the mathematical models for a pseudo-range (P- or C/A-code) or carrier phase observable measurements between receivers will eliminate or greatly reduce satellite clock errors and a large amount of satellite orbit and atmospheric delays.

(2) Between satellites. Single differencing the mathematical models for pseudo-range or carrier phase observable measurements between satellites eliminates receiver clock errors. Single differencing between satellites can be done at each individual receiver during observations as a precursor to double differencing and in order to eliminate receiver clock errors.

(3) Between epochs. Single differencing the mathematical models between epochs takes advantage of the Doppler shift or apparent change in the frequency of the satellite signal by the relative motion of the transmitter and receiver. Single differencing between epochs is generally done in an effort to eliminate cycle ambiguities. There are three forms of single differencing techniques between epochs currently in use today: Intermittently Integrated Doppler (IID), Consecutive Doppler Counts (CDC), and Continuously Integrated Doppler (CID). IID uses a technique whereby Doppler count is recorded for a small portion of the observation period, the Doppler count is reset to zero, and then at a later time the Doppler count is restarted during the observation period. CDC uses a technique whereby Doppler count is recorded for a small portion of the observation period, reset to zero, and then restarted immediately and continued throughout the observation period.

b. Double differencing. Double differencing is actually a differencing of two single differences (as detailed in *a* above). There are two general double differencing processing techniques: receiver-time double and receiver-satellite (see Figure 10-2). Double difference processing techniques eliminate clock errors.

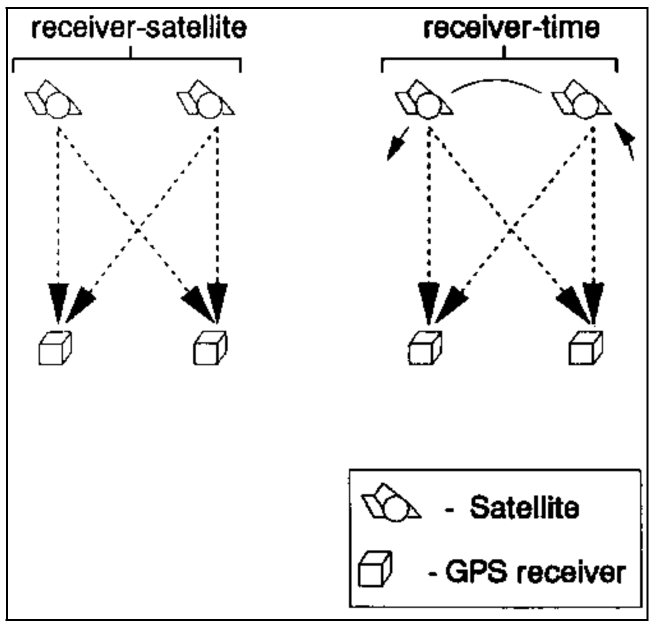


Figure 10-2. Double differencing

(1) Receiver-time double differencing. This technique uses a change from one epoch to the next, in the between-receiver single differences for the same satellite. Using this technique eliminates satellite-dependent integer cycle ambiguities and simplifies editing of cycle slips.

(2) Receiver-satellite double differencing. There are two different techniques that can be used to compute a receiver-satellite double difference. One technique involves using two between-receiver single differences.

This technique also uses a pair of receivers, recording different satellite observations during a survey session and then differencing the observations between two satellites. The second technique involves using two between-satellite single differences. This technique also uses a pair of satellites, but different receivers, and then differences the satellite observations between the two receivers.

c. *Triple differencing*. There is only one triple differencing processing technique: receiver-satellite-time (see Figure 10-3). All errors eliminated during single- and double-differencing processing are also eliminated during triple differencing. When used in conjunction with carrier beat phase measurements, triple differencing eliminates initial cycle ambiguity. During triple differencing, the data are also automatically edited by the software to delete any data that cannot be solved , so that the unresolved data are ignored during the triple difference solution. This feature is advantageous to the user because of the reduction in the editing of data required; however, degradation of the solution may occur if too much of the data are eliminated during triple differencing.

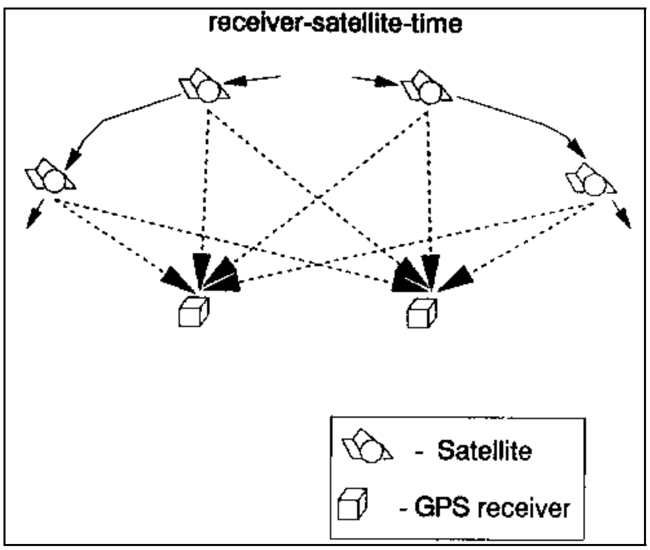


Figure 10-3. Triple differencing

10-5. Baseline Solution by Cycle Ambiguity Recovery

The resultant solution (baseline vector) produced from carrier beat phase observations when differencing resolves cycle ambiguity is called a "fixed" solution. The exact cycle ambiguity does not need to be known to produce a solution; if a range of cycle ambiguities is known, then a "float" solution can be formulated from the range of cycle ambiguities. It is desirable to formulate a fixed solution. However, when the cycle ambiguities cannot be resolved, which occurs when a baseline is between 20 and 65 km in length, a float solution may actually be the best solution. The fixed solution may be unable to determine the correct set of integers (i.e., "fix the integers") required for a solution. Double-differenced fixed techniques can generally be effectively used for positional solutions over short baselines less than 20 km in length. Double differenced float techniques normally can be effectively used for positional solutions for medium-length lines between 20 and 65 km in length.

10-6. Field/Office Data Processing and Verification

a. It is strongly recommended that baselines should be processed daily in the field. This allows the user to identify any problems that may exist. Once baselines are processed, the field surveyor should review each baseline output file. The procedures used in baseline processing are manufacturer-dependent. Certain computational items within the baseline output are common among manufacturers and may be used to evaluate the adequacy of the baseline observation in the field. A list of the triple difference, float double difference, and fixed double difference vectors (*dx-dy-dz*) are normally listed. The geodetic azimuth and distance between the two stations are also listed. The RMS is a quality factor that helps the user determine which vector solution (triple, float, or fixed) to use in an adjustment. The RMS is dependent on the baseline length and the length of time the baseline was observed. Table 10-1 provides guidelines for determining the baseline quality. If the fixed solution meets the criteria in this table, the fixed vector should be used in the adjustment. In some cases the vector passes the RMS test, but after adjustment the vector does not fit into the network. If this occurs, the surveyor should try using the float vector in the adjustments or check to make sure stations were occupied correctly.

b. The first step in data processing is transferring the observation data to a storage device for archiving and/or further processing. Examples of storage devices include a hard disc drive, 5.25-in. disc, 3.5-in. disc, magnetic tape, etc.

c. Once observation data have been downloaded, preprocessing of data can be completed. Pre-processing consists of smoothing/editing the data and ephemeris determination. Smoothing and editing are done to ensure

Table 10-1
Post-processing Criteria

Distance Between Receivers, km	RMS Criteria Formulation (d = distance between receivers)	Formulated RMS Range, cycles	Formulated RMS Range, m
0 - 10	≤(0.02 + (0.004*d))	0.02 - 0.06	0.004 - 0.012
10 - 20	≤(0.03 + (0.003*d))	0.06 - 0.09	0.012 - 0.018
20 - 30	≤(0.04 + (0.0025*d))	0.09 - 0.115	0.018 - 0.023
30 - 40	≤(0.04 + (0.0025*d))	0.115 - 0.14	0.023 - 0.027
40 - 60	≤(0.08 + (0.0015*d))	0.14 - 0.17	0.027 - 0.032
60 - 100	≤0.17	0.17	0.032
> 100	≤0.20	0.20	0.04

Note:

1. These are only general post-processing criteria that may be superseded by GPS receiver/software manufacturer guidelines; consult those guidelines when appropriate.
2. For lines longer than 50 km, dual frequency GPS receivers are recommended to meet these criteria.

data quantity and quality. Activities done during smoothing and editing include determination and elimination of cycle slips; editing gaps in information; and differencing between receivers, satellites, and epochs.

d. Retrieval of post-processed ephemerides may be required depending on the type of receiver used for the survey. Codeless receivers require a post-processed ephemerides file, either that recorded by another GPS receiver concurrent with conduct of the survey or post-processed ephemerides provided by an ephemeris service. Code receivers do not require post-processed ephemerides since they automatically record the broadcast ephemerides during conduct of the survey.

10-7. Post-processing Criteria

Generally, post-processing software will give three solutions: a triple difference, a double-difference fixed solution, and a double-difference float solution. In addition to RDOP as a measurement of the quality of data reduction, methods exist today to gauge the success of an observation session based on data processing done by a differencing process.

a. RMS. RMS is a measurement (in units of cycles or meters) of the quality of the observation data collected during a point in time. RMS is dependent on line length, observation strength, ionosphere, troposphere, and multipath. In general, the longer the line and the more signal interference by other electronic gear, ionosphere, troposphere, and multipath, the higher the RMS will be. A good RMS factor (one that is low, e.g., between 0.01 and 0.2 cycles) may not always indicate good results but is one indication to be taken into account. RMS can generally be used to judge the quality of the data used in the post-processing and the quality of the post-processed baseline vector.

b. Repeatability. Redundant lines should agree to the level of accuracy that GPS is capable of measuring to. For example, if GPS can measure a 10-km baseline to 1 cm $\pm$ 1 ppm, the expected ratio of misclosure would be

$$\frac{0.01\ \text{m} + 0.01\text{m}}{10{,}000} = 1{:}500{,}000$$

Repeated baselines should be near the corresponding

$$\frac{1\ \text{cm} + 1\ \text{ppm}}{\text{baseline}}$$

ratio. See Table 10-2 for an example of repeatability of GPS baselines.

c. Other general information included in a baseline solution.

(1) The following information is typically output from a baseline solution:

(a) Listing of the filename.

(b) Types of solutions (single, double, or triple difference).

Table 10-2
Example of Repeatability of GPS Baselines

Baseline	X	Y	Z	Distance
Line 1	5,000.214	4,000.000	7,680.500	9,999.611
Line 2	5,000.215	4,000.005	7,680.491	9,999.607
Difference	0.001	0.005	0.009	
Ratio = 0.010 / 9,999.6	= 1:967,000			

(c) Satellite availability during the survey for each station occupied.

(d) Ephemeris file used for the solution formulation.

(e) Type of satellite selection (manual or automatic).

(f) Elevation mask.

(g) Minimum number of satellites used.

(h) Meteorological data (pressure, temperature, humidity).

(i) Session time (date, time).

(j) Data logging time (start, stop).

(k) Station information: location (latitude, longitude, height), receiver serial number used, antenna serial number used, ID numbers, antenna height.

(l) RMS.

(m) Solution files: Δx, Δy, Δz between stations, slope distance between stations, Δlatitude, Δlongitude between stations, distance between stations, and Δheight.

(n) Epoch intervals.

(o) Number of epochs.

(2) Sample static baseline formulations from two equipment manufacturers, Ashtech, Inc., (GPPS) and Trimble Navigation (GPSurvey), are shown in Figures 10-4 and 10-5, respectively. The baseline formulations have been annotated with the conventions in (a)-(o) above as an aid in an explanation of the results.

10-8. Field/Office Loop Closure Checks

Post-processing criteria are aimed at an evaluation of a single baseline. In order to verify the adequacy of a group of connected baselines, one must perform a loop closure on the baselines formulated. When GPS baseline traverses or loops are formed, their linear (internal) closure should be determined in the field. If job requirements are less than Third-Order (1:10,000 or 1:5,000), and the internal loop/traverse closures are very small, a formal (external) adjustment may not be warranted.

a. Loop closure software packages. The internal closure determines the consistency of the GPS measurements. Internal closures are applicable for loop traverses and GPS networks. It is required that one baseline in the loop be independent. An independent baseline is observed during a different session or different day. Today, many of the better post-processing software packages come with a loop closure program. Refer to the individual manufacturer post-processing user manuals for a discussion on the particulars of the loop closure program included with the user hardware.

b. General loop closure procedure. If the user post-processing software package does not contain a loop closure program, the user can perform a loop closure as shown below.

(1) List the Δx, Δy, and Δz and length of the baseline being used in a table of the form shown in Table 10-3.

(2) Sum the Δx, Δy, Δz, and distance components for all baselines used in the loop closure. For instance, for the baselines in Table 10-3, the summation would be $\Sigma\Delta x$, $\Sigma\Delta y$, $\Sigma\Delta z$, and Σ*Distances* or $(\Delta x\#1 + \Delta x\#2 + \Delta x\#3)$, $(\Delta y\#1 + \Delta y\#2 + \Delta y\#3)$, $(\Delta z\#1 + \Delta z\#2 + \Delta z\#3)$, and $(\Delta Distance\#1 + \Delta Distance\#2 + \Delta Distance\#3)$, respectively.

(3) Once summation of the Δx, Δy, Δz, and Δ*Distance* components has been completed, the square of each of the summations should be added together and the square root of this sum then taken. This resultant value is the misclosure vector for the loop. This relationship can be expressed in the following manner:

```
Ashtech, Inc. GPPS-L          Program: LINECOMP        Version: 4.5.00
                             Tue Jan 25 10:16:25 1994
_______________________________________________________________________
Project information
GPS Survey                |25-character project name  [ The | is in column 26. ]
3203C                     |5-character session name
Project information

Known-station parameters
00                        |Receiver identifier used in "LOGTIMES" file
000000                    |Project station number
MANT                      |4-character short name
FIXED STATION             |25-character long name
564 270 DCO PIC___________|25-character comment field
0                         |Position extraction (0=below,1=U-file,2=proj. file)
N  40  2 18.36587         |Latitude deg-min-sec  (g=good;b=bad)
E 285 56 49.57251         |E-Longitude deg-min-sec (g=good;b=bad)
W  74  3 10.42749         |W-Longitude deg-min-sec (g=good;b=bad)
   -12.0807               |Ellipsoidal height  (m) (g=good;b=bad)
     0.0000               |North antenna offset(m)
     0.0000               |East antenna offset (m)
  1.4300  0.0000  0.0000  |Vert antenna offset (m): slant/radius/added_offset
    20.0                  |Temperature (degrees C)
    50.0                  |Humidity (percent)
  1010.0                  |Pressure (millibars)
UMANTC93.320              |Measurement filename (restricted to 24 characters)
Known-station parameters

Unknown-station parameters
00                        |Receiver identifier used in "LOGTIMES" file
000000                    |Project station number
FTM1                      |4-character short name
UNKNOWN STATION           |25-character long name
564 270 DCO PIC___________|25-character comment field
0                         |Position extraction (0=below,1=U-file,2=proj. file)
N  40 18 45.82336         |Latitude deg-min-sec  (g=good;b=bad)
E 285 57 46.72853         |E-Longitude deg-min-sec (g=good;b=bad)
W  74  2 13.27147         |W-Longitude deg-min-sec (g=good;b=bad)
   -20.5991               |Ellipsoidal height  (m) (g=good;b=bad)
     0.0000               |North antenna offset(m)
     0.0000               |East antenna offset (m)
  0.0000  0.0000  0.0000  |Vert antenna offset (m): slant/radius/added_offset
    20.0                  |Temperature (degrees C)
    50.0                  |Humidity (percent)
  1010.0                  |Pressure (millibars)
UFTM1C93.320              |Measurement filename (restricted to 24 characters)
Unknown-station parameters

Run-time parameters
   10                     |First epoch to process
   -1                     |Final epoch to process (-1 = last available)
15.0                      |Elevation cutoff angle (degrees)
1                         |Data to process (0=Wdln;1=L1;2=L2;3=L1c;6=RpdSt)
0.010000                  |Convergence criterion (meters)
00 00 00 00 00 00 00      |Omit these satellites (up to 7)
10                        |Maximum iterations for tlsq and dlsq
00 00 00 00 00 00 00      |Forbidden reference SVs (up to 7)
yes                       |Apply tropo delay correction
Run-time parameters
```

Figure 10-4. Sample static baseline formulation (Ashtech, Inc., GPPS-L) (Sheet 1 of 5)

```
LINECOMP 4.5.00 12/11/92

FIXED U-File from P-Code receiver.
UNKWN U-File from P-Code receiver.

FIXED U-File used BROADCAST orbits.
UNKWN U-File used BROADCAST orbits.

Common start of two UFILES: 1993/11/16 20:23:60.00
Common end   of two UFILES: 1993/11/16 22:00:20.00
    Selected first epoch:  10
    Selected last  epoch:  290
For SV  1 there are   280 triple-difference measurements.
For SV  5 there are   181 triple-difference measurements.
For SV 12 there are   136 triple-difference measurements.
For SV 15 there are   152 triple-difference measurements.
For SV 20 there are   181 triple-difference measurements.
For SV 21 there are   181 triple-difference measurements.
For SV 23 there are   181 triple-difference measurements.
For SV 25 there are   181 triple-difference measurements.
Epoch interval (seconds): 20.000000


THE TRIPLE DIFFERENCE SOLUTION (L1)
Measure of geometry: 0.712832
num_meas =  1192        num_used =  1191         rms_resid = 0.002725(m)
Post-Fit Chisq =  1403.765           NDF      =    11.028


  Sigmax (m):      0.347912
  Sigmay (m):      0.646995
  Sigmaz (m):      0.327369
  x     y     z
x 1.00
y 0.17y 1.00
z 0.12z-0.50z 1.00

del_station: -0.000007 -0.000001 0.000027
     Station1: FIXED STATION                Station2: UNKNOWN STATION
             (00000)    (MANT)                        (00000)    (FTM1)
 Latitude:  40.03843496  40  2 18.36587          40.31281330  40 18 46.12789
 E-Long  : 285.94710348 285 56 49.57251         285.96293196 285 57 46.55506
 W-Long  :  74.05289652  74  3 10.42749          74.03706804  74  2 13.44494
 E-Height: -12.0807                               -2.8736

 Baseline vector:     -4104.5950     19261.5243     23284.3880

 Mark1_xyz  :  1343513.8259  -4701767.9098   4081246.0717
 Az1 El1 D1 :        2.52867       -0.1200     30496.1759
 E1 N1 U1   :     1350.8948     30465.6429        9.2071
 Mark2_xyz  :  1339409.2309  -4682506.3855   4104530.4598
 Az2 El2 D2 :      182.53888       -0.1546     30496.1759
 E2 N2 U2   :    -1345.4669    -30467.1353       -9.2071

Double-Difference Epochs:
  Prn:   1  Start epoch:   11  End epoch:  290
  Prn:   5  Start epoch:  110  End epoch:  290
  Prn:  12  Start epoch:  110  End epoch:  249
  Prn:  15  Start epoch:  139  End epoch:  290
  Prn:  20  Start epoch:  110  End epoch:  290
```

Figure 10-4. (Sheet 2 of 5)

```
    Prn:  21  Start epoch:  110  End epoch:  290
    Prn:  23  Start epoch:  110  End epoch:  290
    Prn:  25  Start epoch:  110  End epoch:  290


  THE FLOAT DOUBLE DIFFERENCE SOLUTION (L1)
  Measure of geometry: 0.195687     Wavelength = 0.190294 (m/cycle)
  num_meas =  1200        num_used =  1200         rms_resid = 0.013991(m)
  Post-Fit Chisq =   186.429             NDF       =    11.111

  Reference SV:  1
    SV     Ambiguity        FIT    Meas       SV     Ambiguity        FIT    Meas
     5        59386.483f  0.054    182       12      -1227312.585f  0.050    138
    15      2121069.816f  0.097    152       20        531426.734f  0.072    182
    21      -184904.908f  0.073    182       23      -1075927.194f  0.062    182
    25       646212.381f  0.093    182

    Sigmax (m):       0.049793
    Sigmay (m):       0.056987
    Sigmaz (m):       0.026423
    SigmaN (cy):      0.283527
    SigmaN (cy):      0.289386
    SigmaN (cy):      0.245180
    SigmaN (cy):      0.217266
    SigmaN (cy):      0.134735
    SigmaN (cy):      0.204750
    SigmaN (cy):      0.196954
    x     y     z     N     N     N     N     N     N     N
  x 1.00
  y 0.19y 1.00
  z 0.08z-0.30z 1.00
  N 0.77N 0.74N-0.23N 1.00
  N 0.53N 0.90N-0.22N 0.92N 1.00
  N-0.81N 0.35N-0.35N-0.27N 0.01N 1.00
  N 0.87N 0.27N-0.35N 0.80N 0.58N-0.57N 1.00
  N 0.39N-0.52N-0.30N 0.04N-0.24N-0.51N 0.55N 1.00
  N 0.70N 0.11N-0.56N 0.62N 0.39N-0.47N 0.91N 0.71N 1.00
  N-0.68N-0.57N-0.38N-0.71N-0.70N 0.41N-0.40N 0.35N-0.09N 1.00

  del_station: -0.000000 -0.000000 0.000000
      Station1: FIXED STATION                  Station2: UNKNOWN STATION
               (00000)     (MANT)                        (00000)     (FTM1)
   Latitude:  40.03843496  40  2 18.36587          40.31281268  40 18 46.12563
   E-Long   : 285.94710348 285 56 49.57251        285.96293166 285 57 46.55396
   W-Long   :  74.05289652  74  3 10.42749         74.03706834  74  2 13.44604
   E-Height: -12.0807                               -2.8299

   Baseline vector:     -4104.5984     19261.4419     23284.3633

   Mark1_xyz  :  1343513.8259  -4701767.9098   4081246.0717
   Az1 El1 D1 :        2.52863        -0.1199     30496.1054
   E1 N1 U1   :     1350.8687     30465.5734         9.2508
   Mark2_xyz  :  1339409.2275  -4682506.4679   4104530.4350
   Az2 El2 D2 :      182.53884        -0.1547     30496.1054
   E2 N2 U2   :    -1345.4410    -30467.0660        -9.2508


  AMBIGUITY RESOLUTION
                          1          2          3          4
  Abs Contrast          0.000      0.000      0.000      0.000
```

Figure 10-4. (Sheet 3 of 5)

```
Contrast                              99.999     100.000     100.000
Change Chi2           318.829        907.189    1231.184    1556.459
Bias S 1: 5             59387          59385       59387       59387
Bias S 1:12          -1227312       -1227314    -1227312    -1227312
Bias S 1:15           2121070        2121070     2121069     2121071
Bias S 1:20            531427         531426      531427      531427
Bias S 1:21           -184905        -184905     -184905     -184905
Bias S 1:23          -1075927       -1075928    -1075927    -1075927
Bias S 1:25            646212         646213      646212      646213
NDF=127.0000 Chi2=186.4289
                            1              2           3           4
Abs Contrast            0.000          0.000       0.000       0.000
Contrast                              99.999     100.000     100.000
Change Chi2           298.148        843.456    1086.524    1100.925
Bias S 1:12          -1227312       -1227314    -1227313    -1227313
Bias S 1:15           2121070        2121070     2121069     2121071
Bias S 1:20            531427         531426      531427      531426
Bias S 1:21           -184905        -184905     -184905     -184905
Bias S 1:23          -1075927       -1075928    -1075927    -1075928
Bias S 1:25            646212         646213      646212      646213
NDF=127.0000 Chi2=186.4289
                            1              2           3           4
Abs Contrast            0.004          0.000       0.000       0.000
Contrast                              99.986     100.000     100.000
Change Chi2           190.078        526.018     746.284    1076.670
Bias S 1:15           2121070        2121069     2121070     2121069
Bias S 1:20            531427         531427      531426      531426
Bias S 1:21           -184905        -184905     -184905     -184905
Bias S 1:23          -1075927       -1075927    -1075928    -1075928
Bias S 1:25            646212         646212      646213      646212
NDF=127.0000 Chi2=186.4289
                            1              2           3           4
Abs Contrast            4.563          0.000       0.000       0.000
Contrast                             100.000     100.000     100.000
Change Chi2           128.751       2529.042    3851.923    5153.774
Bias S 1: 5             59387          59388       59387       59387
Bias S 1:12          -1227312       -1227311    -1227311    -1227313
NDF=132.0000 Chi2=376.5065


THE FIXED DOUBLE DIFFERENCE SOLUTION (L1)
Measure of geometry: 0.038900     Wavelength = 0.190294 (m/cycle)
num_meas =  1200          num_used =  1188          rms_resid = 0.021554(m)
Post-Fit Chisq =    435.849              NDF       =      11.000

Reference SV:  1                     Integer Search Ratio =    99.986
  SV      Ambiguity          FIT     Meas       SV      Ambiguity          FIT     Meas
   5        59387.000X     0.066     182        12       -1227312.000X    0.070     138
  15      2121070.000X     0.195     140        20         531427.000X    0.065     182
  21      -184905.000X     0.067     182        23       -1075927.000X    0.080     182
  25       646212.000X     0.176     182

  Sigmax (m):       0.009106
  Sigmay (m):       0.015190
  Sigmaz (m):       0.016909
  x      y      z
x 1.00
y-0.37y 1.00
z 0.40z-0.71z 1.00
```

Figure 10-4. (Sheet 4 of 5)

```
del_station: 0.001087 -0.002400 0.000191
     Station1: FIXED STATION                Station2: UNKNOWN STATION
                (00000)     (MANT)                    (00000)     (FTM1)
 Latitude:  40.03843496  40   2 18.36587          40.31281315  40 18 46.12733
 E-Long  : 285.94710348 285  56 49.57251         285.96293257 285 57 46.55727
 W-Long  :  74.05289652  74   3 10.42749          74.03706743  74  2 13.44273
 E-Height: -12.0807                                -2.9282

 Baseline vector:     -4104.5533     19261.5680     23284.3397

 Mark1_xyz  :  1343513.8259  -4701767.9098   4081246.0717
 Az1 El1 D1 :        2.52877        -0.1201     30496.1610
 E1 N1 U1   :     1350.9471     30465.6258         9.1525
 Mark2_xyz  :  1339409.2726  -4682506.3418   4104530.4115
 Az2 El2 D2 :      182.53898        -0.1545     30496.1610
 E2 N2 U2   :    -1345.5190    -30467.1180        -9.1525
Tue Jan 25 10:18:17 1994
```

Figure 10-4. (Sheet 5 of 5)

Project Name:	ftm1
Processed:	Tuesday, January 25, 1994 11:17
	WAVE Baseline Processor, version 1.01
Summary Reference Index:	1
Fixed Station:	MANT
Antenna Height (meters):	1.430 [True Vertical]
Data file:	MANT320C.DAT
Floating Station:	FTM1
Antenna Height (meters):	0.000 [True Vertical]
Data file:	FTM1320C.DAT
Start Time:	11/16/93 20:21:40 GPS (723 246100)
Stop Time:	11/16/93 22:00:20 GPS (723 252020)
Occupation Time:	0 01:38:40
Measurement Epoch Interval (seconds):	20.00
Solution Type:	Receiver/satellite double difference
	Fixed integer phase ambiguity
	Iono free carrier phase
Solution Acceptability:	Passed
Number of Observations / Number Rejected:	1838 / 0 (0.00% of Total Observations)

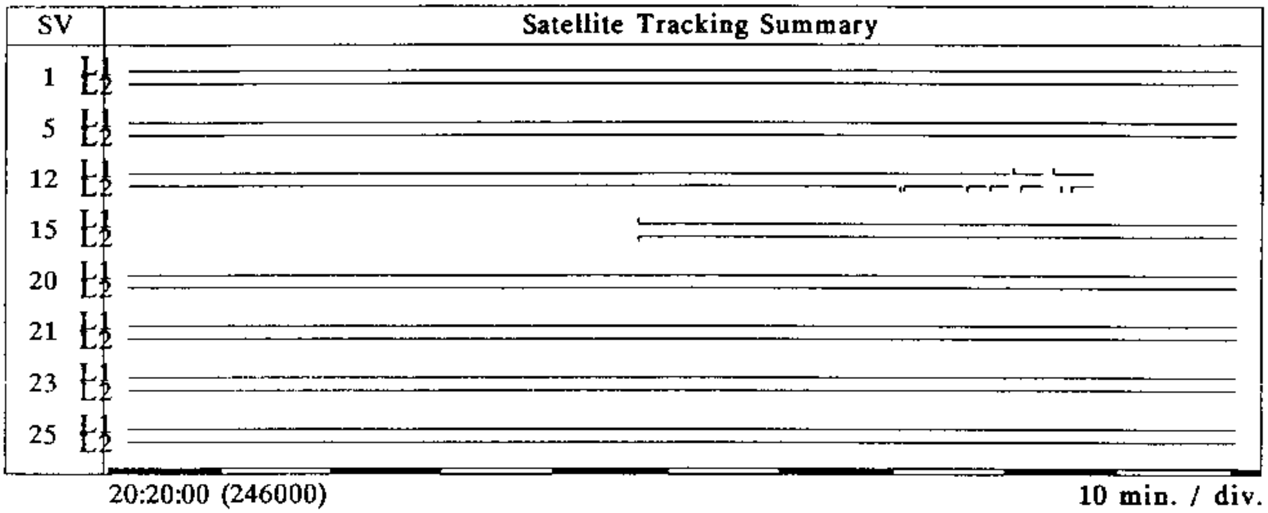
Baseline Slope Distance (meters):	30496.196					
	Forward			Backward		
Normal Section Azimuth:	2° 31' 42.850578"			182° 32' 19.610607"		
Vertical Angle:	-0° 07' 12.582816"			-0° 09' 16.140268"		
Baseline Components (meters):	dn	30466.437	de	1345.414	du	-63.957
	dx	-4104.555	dy	19261.587	dz	23284.370
Standard Deviations:		5.303799E-004		9.044810E-004		8.225305E-004
Aposteriori Covariance Matrix:		2.813028E-007				
		-2.038846E-007		8.180858E-007		
		1.759316E-007		-4.827601E-007		6.765565E-007

Reference Variance:	0.633
Variance Ratio 2nd Best/Best Ambiguity Candidate:	28.0
RMS (meters):	0.014

Figure 10-5. Sample static baseline formulation (Trimble Navigation (GP Survey) (Sheet 1 of 3)

Project: ftm1
Processed: Tuesday, January 25, 1994 11:17 WAVE 1.01

Fixed Sta
Position: 40■ 02' 18.244439" N 74■ 03' 11.
X= 1343486.892 Y= -4701771.345



Float Sta
Position: 40■ 18' 46.008533" N 74■ 02' 14.
X= 1339382.336 Y= -4682509.759

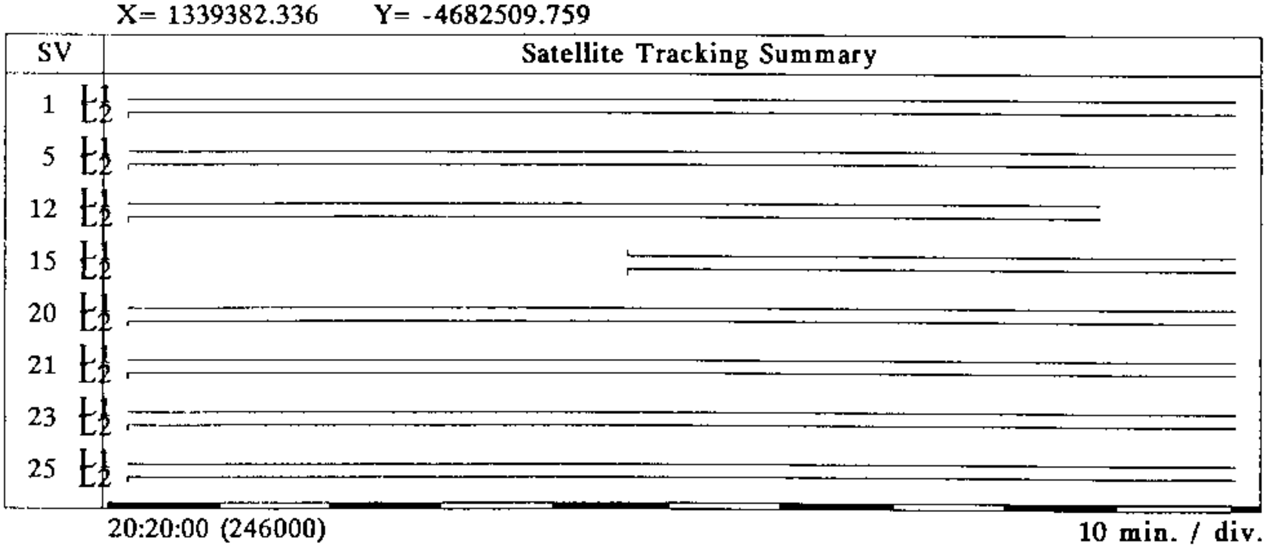


Figure 10-5. (Sheet 2 of 3)

Project: ftm1
Processed: Tuesday, January 25, 1994 11:17 WAVE 1.01

Station si
Shading i

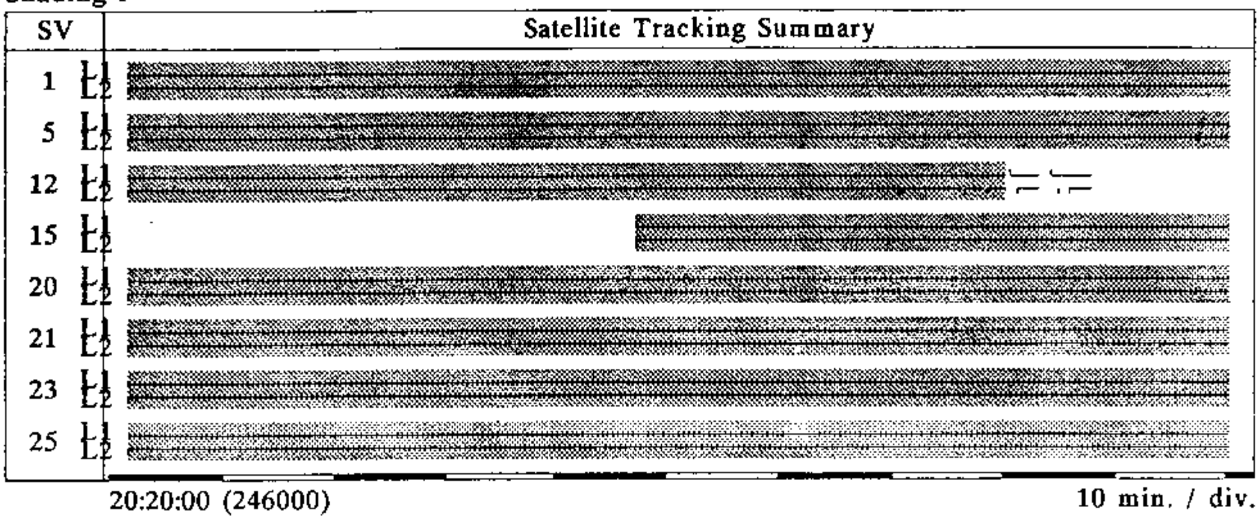


Figure 10-5. (Sheet 3 of 3)

Table 10-3
Loop Closure Procedure

Baseline	Julian Day	Session	Δx	Δy	Δz	ΔDistance
#1	Day	#	Δx #1	Δy #1	Δz #1	Distance #1
#2	Day	#	Δx #2	Δy #2	Δz #2	Distance #2
#3	Day	#	Δx #3	Δy #3	Δz #3	Distance #3

$$m = \sqrt{(\Sigma\Delta x^2) + (\Sigma\Delta y^2) + (\Sigma\Delta z^2)} \qquad (10\text{-}1)$$

where

m = misclosure for the loop

$\Sigma\Delta x$ = sum of all Δx vectors for baselines used

$\Sigma\Delta y$ = sum of all Δy vectors for baselines used

$\Sigma\Delta z$ = sum of all Δz vectors for baselines used

(4) The loop misclosure ratio may be calculated as follows:

$$Loop\ misclosure\ ratio = \frac{m}{L} \qquad (10\text{-}2)$$

where

L = total loop distance (perimeter distance)

(5) The resultant value can be expressed in the following form:

1: Loop Misclosure Ratio

with all units for the expressions being in terms of the units used in the baseline formulations (e.g., m, ft, mm, etc.).

c. Sample loop closure computation. Figure 10-6 shows two loops which consist of four stations. During session A on day 065, three GPS receivers observed the baselines between stations 01, 02, and 03 for approximately 1 hr. The receivers were then turned off and the receiver at station 01 was moved to station 04. The tripod heights at stations 02 and 03 were adjusted. The baselines between stations 02, 03, and 04 were then observed during session B, day 065. Stations 01 and 04 were known control stations. This provided an independent baseline for both loops.

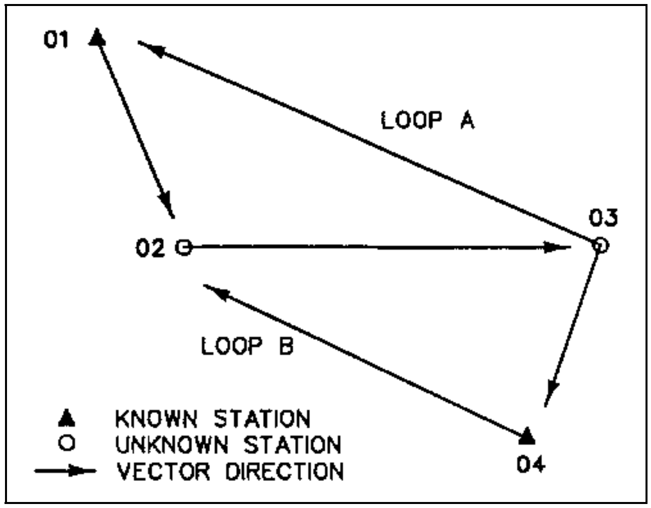


Figure 10-6. Internal loop closure diagram

(1) The closure for loop 01-02-03 is computed with the vectors 01-02 and 01-03, day 065, session A, and the vector 02-03, day 065, session B. The vector 02-03 from session B provides an independent baseline. The loop closure is determined by arbitrarily assigning coordinate values of zero to station 01 (X=0, Y=0, Z=0). The vector from 01-02 is added to the coordinates of station 01. The vector from 02-03, session B, is added to the derived coordinates of station 02. The vector from 03-01 is then added to the station coordinates of 02. Since the starting coordinates of station 01 were arbitrarily chosen as zero, the misclosure is then the computed coordinates of Station 04 (*dx*, *dy*, *dz*). The vector data are listed in Table 10-4.

(2) To determine the relative loop closure, the square root of the sum of the squares of the loop misclosures (*mx*, *my*, *mz*) is divided into the perimeter length of the loop:

Table 10-4
Vector Data for Stations 01, 02, and 03

Baseline	Julian Day	Session	ΔX	ΔY	ΔZ	ΔDistance
01-02	065	A	-4077.865	-2877.121	-6919.829	8531.759
02-03	065	B	7855.762	-3129.673	688.280	8484.196
03-01	065	A	-3777.910	6006.820	6231.547	9443.869

$$\textit{Loop misclosure ratio} = \frac{\left(\Delta x^2 - \Delta y^2 - \Delta z^2\right)^{0.5}}{L} \qquad (10\text{-}3)$$

Where the PD = distance 01-02 + distance 02-03 + distance 03-01, or:

$$PD = 8531.759 + 8484.196 + 9443.869$$

$$= 26{,}459.82$$

And where distance 03-01 is computed from:

$$(-3777.91^2 + 6006.820^2 + 6231.547^2)^{0.5}$$

$$= 9443.869$$

(Other distances are similarly computed.)

Summing the misclosures in each coordinate:

Δx = -4077.865 + 7855.762 - 3777.910 = -0.0135

Δy = -2877.121 - 3129.673 + 6006.820 = +0.0264

Δz = -6919.829 + 688.280 + 6231.547 = -0.0021

then

$$(\Delta x^2 + \Delta y^2 + \Delta z^2)^{0.5} = 0.029$$

Loop misclosure ratio = 0.029/26,459.82

or (approximately) 1 part in 912,000 (1:912,000)

(3) This example is quite simplified; however, it illustrates the necessary mechanics in determining internal loop closures. The values *DX*, *DY*, and *DZ* are present in the baseline output files. The perimeter distance is computed by adding the distances between each point in the loop.

d. External closures. External closures are computed in a similar manner to internal loops. External closures provide information on how well the GPS measurements conform to the local coordinate system. Before the closure of each traverse is computed, the latitude, longitude, and ellipsoid height must be converted to geocentric coordinates (X,Y,Z), using the algorithms given in Chapter 11. If the ellipsoid height is not known, geoid modeling software can be used with the orthometric height to get an approximate ellipsoid height. The external closure will aid the surveyor in determining the quality of the known control and how well the GPS measurements conform to the local network. If the control stations are not of equal precision, the external closures will usually reflect the lower order station. If the internal closure meets the requirements of the job, but the external closure is poor, the surveyor should suspect that the known control is deficient and an additional known control point should be tied into the system.

10-9. Data Management (Archival)

The raw data are defined as data recorded during the observation period. Raw data shall be stored on an appropriate medium (floppy disk, portable hard drive, magnetic tape, etc.). The raw data and the hard copy of the baseline reduction (resultant baseline formulations) shall be stored at the discretion of each USACE Command.

10-10. Flow Diagram

When processing GPS observational data, the progress should generally follow the path shown in Figure 10-7.

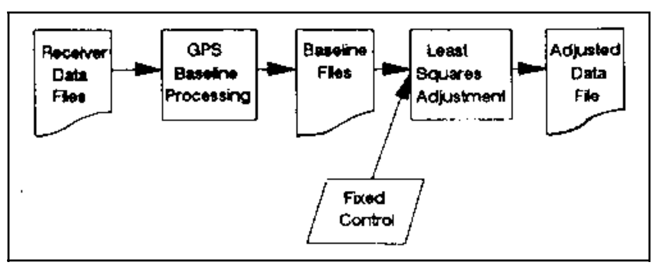


Figure 10-7. GPS data processing flowchart